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RESEARCH AND DEVELOPMENT TECHNICAL REPORT

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ECCM PERFORMANCE OF THE DIGITAL MICROWAVE RADIO UNDER ADVERSE WEATHER CONDITIONS

JAMES E. BARTOW

CENTER FOR COMMUNICATIONS SYSTEMS

MAY 1982

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The Digital Microwave Radio will operate at 15 GHz and will provide multichannel ECCM radio communications. Rain attenuation causes severe signal reduction in this band. The communication reliability, considering multipath and rain attenuation, is determined for a radio relay network and the improvement in reliability by use of alternate routing is estimated.

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ECCM PERFORMANCE OF THE DIGITAL MICROWAVE RADIO UNDER ADVERSE WEATHER CONDITIONS

by James E. Bartow

U.S. Army Communications-Electronics Command, Fort Monmouth, NJ

Summary. The Digital Microwave Radio (DMR) will use a null steering antenna, spread spectrum modulation and coding to provide ECCM multichannel communications. Since it will operate at 15 GHz, it will be affected by atmospheric attenuation from water vapor, fog, water film on antennas and in particular from rain. The fade margins necessary to overcome these attenuations and multipath fading are determined in this paper. It is found that the rain attenuation causes severe attenuation (71 dB) for short periods (.03% of the time) on a 50 km radio link. It is noted that the size of rain cells, when rain rate is high, is small compared to the communication path lengths. The combined power of the jamming signals, when two widely spaced jammers are considered, is less severely attenuated. Only 16 dB of jammer signal attenuation can be expected .03% of the time, leaving a net margin of 55 dB required in signal-to-jamming ratio. Alternate routing is proposed and it is shown that the required margin to compensate for the rain attenuation difference between desired and jamming paths is reduced to 32 dB for .03% outages.

The overall communication reliability, considering all propagation losses and multipath, is determined for the network and the improvement obtained by use of alternate routing is estimated. It is concluded that alternate routing is a valuable tool to reduce radio fade margin requirements, especially at frequencies where rain attenuation becomes significant.

1. Introduction. The U.S. Army Digital Microwave Radio program is intended to provide ECM resistant multichannel microwave communication circuits in the Corps and Army areas in the 1990's. It will provide the functions now accomplished by the AN/GRC-144, and will provide a new capability for the Defense Communication system.

The DMR will incorporate techniques for reducing the effectiveness of jamming, including a steerable null antenna system, a spread spectrum modem and error correction coding. Since the DMR will operate in the 15 GHz as well as the 5 GHz frequency band, atmospheric attenuation is a significant factor in designing the system. The radio set will include adaptive techniques which will respond to varying jamming levels to provide

the optimum throughput. The radio set will also respond to varying signal levels resulting from fog and rain attenuation conditions along the path. Especially at 15 GHz, the effect of rain attenuation on the desired signal and the jamming signal is a major factor in the system design and in the network performance.

The adaptive antenna processor performs its function by controlling the amplitude and phase of signals received from several antenna ports. In the presence of multipath propagation, the amplitude and phase of the received signals will vary with time and frequency. The antenna must be capable of adapting to these variable conditions to maximize the output signal-to-jamming ratio.

The spread spectrum modem is designed to use the available spectrum in an optimum manner. The receiver uses techniques to correlate the incoming signal with a locally generated waveform. The desired signal is recovered while the uncorrelated jamming signal is reduced by the ratio of spread to information bandwidth.

2. Purpose. The purpose of this report is to analyze the effects of propagation on the design and performance of the DMR. The need for wide spectrum occupancy rules out the use of frequencies below 10 GHz in many areas. As a result frequencies in the 15 GHz range have been chosen for DMR use. This report will review the effects of weather conditions on Ku-band propagation. The primary concern is the rain attenuation which will be experienced. A model of rainstorms is formulated to cover the ranges of rain rate of primary concern. This model is then used to determine the propagation effects on jamming and desired signals and the benefit to be obtained by alternate routing to reduce circuit outages.

3. The primary sources of attenuation of radio signals at 15 GHz are rain, fog, gaseous absorption, fading and water film on radomes. The gaseous absorption is caused by oxygen and water vapor (Rice, 1967).[1] The attenuation from these two sources is shown in Figure 1 (Bussey, 1950)[2]. At a range of 50 km at 15 GHz this loss amounts to about 3.2 dB for 1% of the time. It will be assumed in this report that the typical jammer path length is at least 100 km. Therefore, the jamming signal will suffer a 6.4 dB loss (or more) for 1% of the time.

Gaseous atmospheric attenuation depends on the density of oxygen and water vapor, both of which diminish with altitude. Water vapor also varies with climate and season. Rice (1967)[1] presents a general method for calculating attenuation from these causes.

Attenuation from fog is caused by absorption of water droplets in the atmosphere. Gunn and East (1954)[3] calculate the loss and state that the absorption coefficient is proportional to the liquid water content. The attenuation is significant only when the droplets are liquid. Below freezing the loss is insignificant. The fog attenuation coefficient as a function of RF frequency is given in Figure 2. It can be seen that at 15 GHz the coefficient is 0.16 dB/km per g/m^3. This is an average value,

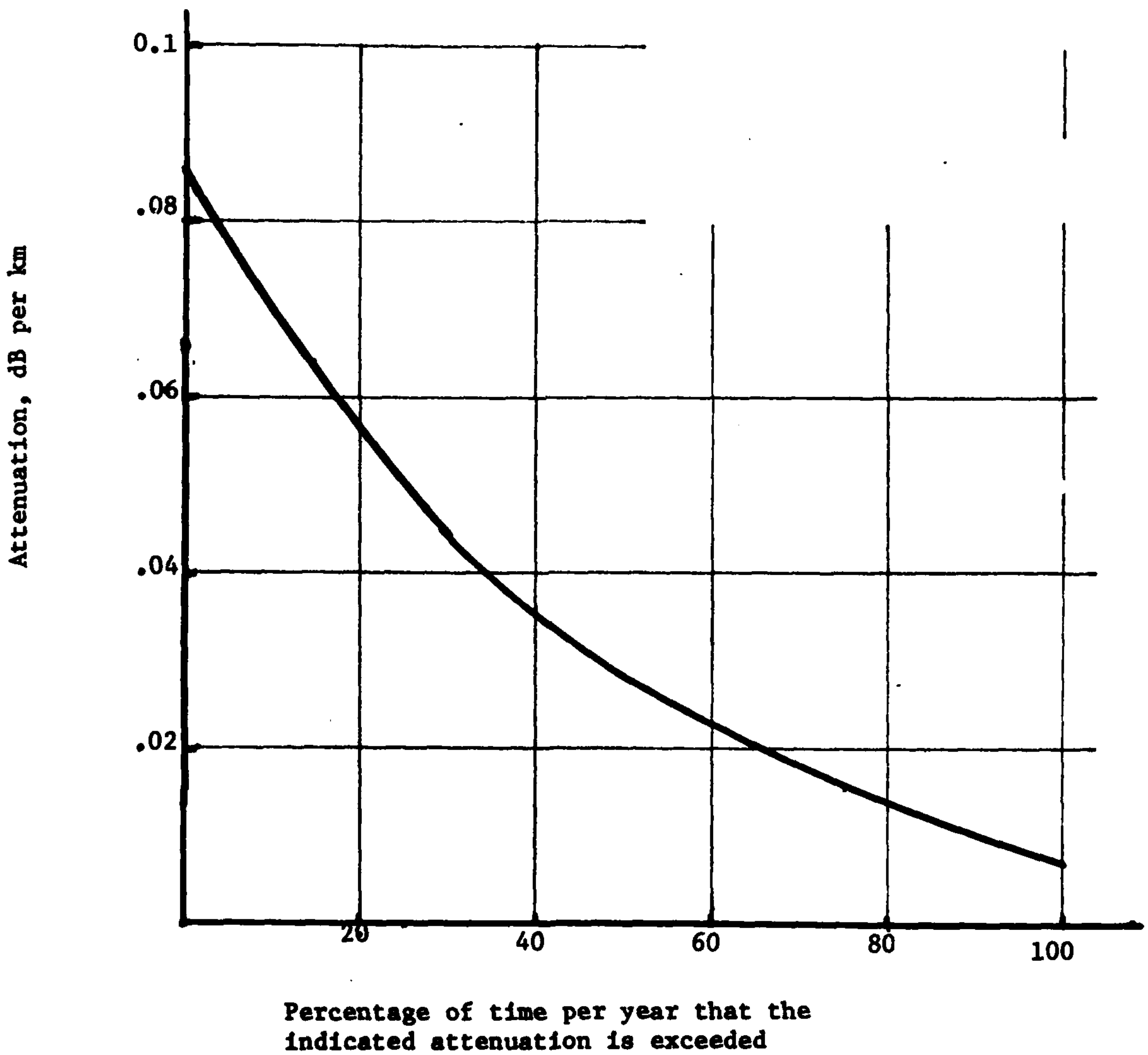

Figure 1. Gaseous Attenuation values at Washington D.C. at 15 GHz (Interpolated from Bussey)

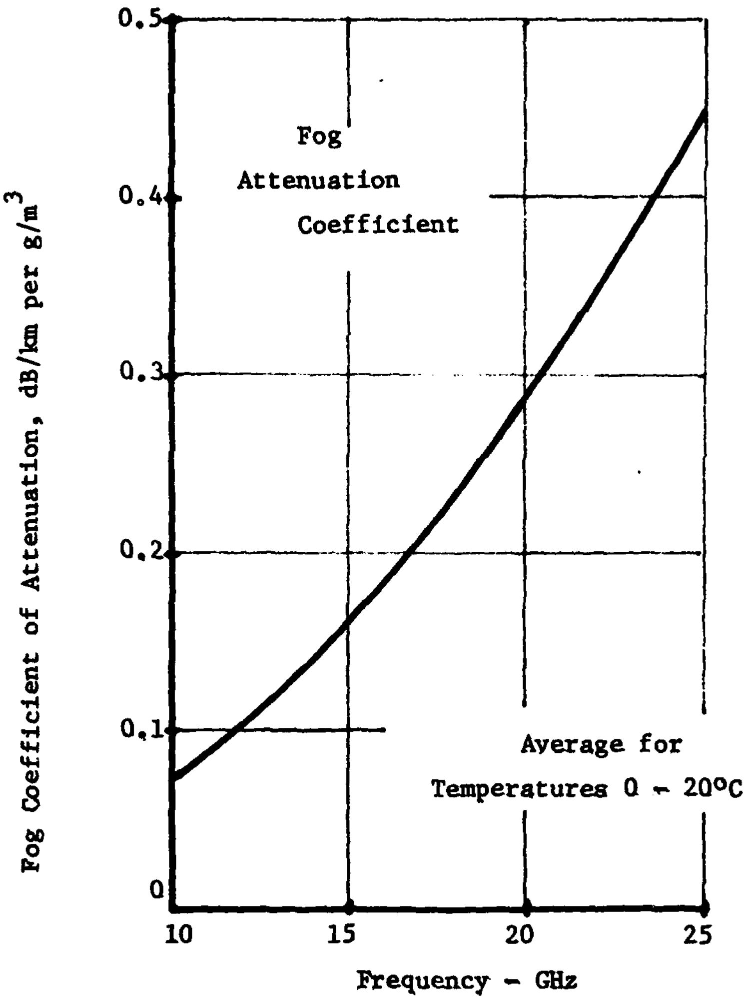

Figure 2. Coefficient of Fog Attenuation (after Gunn & East)

for a droplet temperature of 10°C. The value increases to 0.22 dB/km per g/m^3 at 0°C and is negligibly low below that value.

The water content of fog can vary from 0.05 to 1.5 g/m^3 (Krasikov, 1956)[4]. However, Petterson (1941)[5] states that the content of liquid water seldom exceeds 0.3 g/m^3. At this water content the fog attenuation is 0.048 dB/km at 10°C, at 15 GHz.

For a typical 50 km path the maximum attenuation from fog is 2.4 dB, under these assumptions. The jammer attenuation may be 4.8 dB or more, but the frequency of occurrence of widespread fog is usually quite small. It is, of course, highly dependent on geographical location and climate.

a. The signal received over microwave radio paths varies with time as a result of irregularities in the refractive index of the atmosphere. Barnett, W.T., 1972[6] has found that the fading depth is proportional to D^3/λ where D is the path length and λ the wavelength. This fading is characteristic of multiple path propagation caused by an atmospheric layer of abnormal refractivity located in the transmission path. At 15 GHz the predicted fading characteristics are as shown in Figure 3. It is noted that fades of 28 dB depth are predicted 0.1% of the time. 18 dB depth fades may occur 1% of the time. Also note that signals 5 dB above normal may occur 10% of the time and 10 dB above normal about 1.0% of the time. The latter effect may cause an increase in jamming signal level of 5 to 10 dB while not necessarily increasing the desired signal during this period. In fact for other than main beam jamming, it may be expected that the periods of enhancement of two signals will be uncorrelated.

b. Water film on an antenna radome or feed diaphram will cause additional attenuation. Hogg and Chu (1975)[7] state that a water film of 0.1 mm thickness will cause a loss of 5 dB at 15 GHz. The loss through a film of water is indicated in Figure 4. The attenuation of a receiving antenna radome will of course reduce jamming and desired signals equally. However, the loss in signal through a transmitting antenna radome represents an increase in J/S ratio, since the jamming transmitter is not likely to simultaneously suffer from this attenuation.

c. Rain is the most significant cause of signal propagation attenuation at 15 GHz. The reduction in received signal will vary from .002 dB/km at a rate of 0.1 mm/hr to 7 dB/km at a rate of 100 mm/hr (Medhurst, 1965).[8] The variation in attenuation is shown in Figure 5. The time distribution of rain intensity varies widely with geographic location. Some values of rain intensity exceeded 0.1% of the time for various locations (Burroughs, 1967)[9] are:

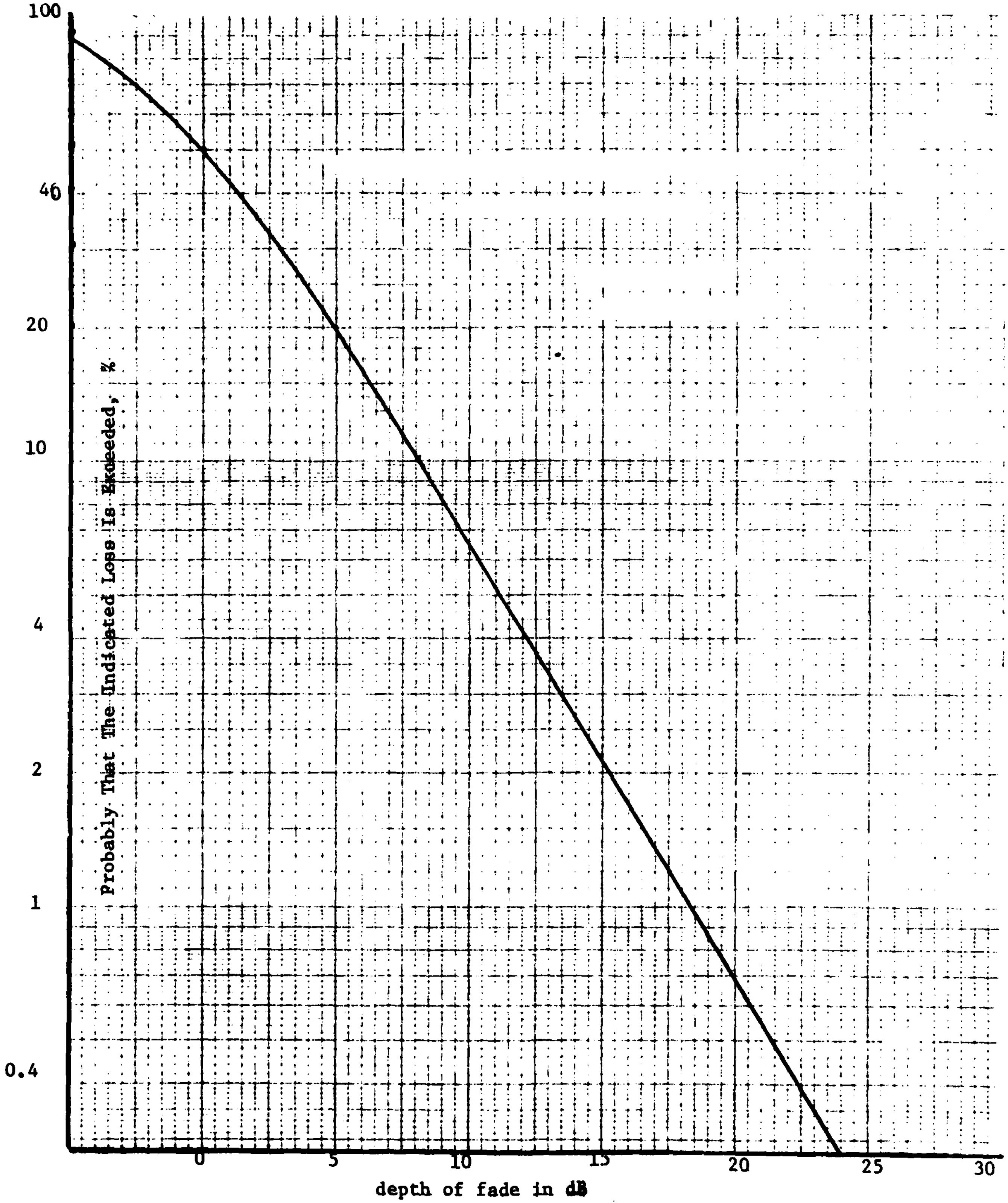

Figure 3. Line of Sight Multipath Fading Statistics at 15 GHz (Nakagami-Rice Distribution)

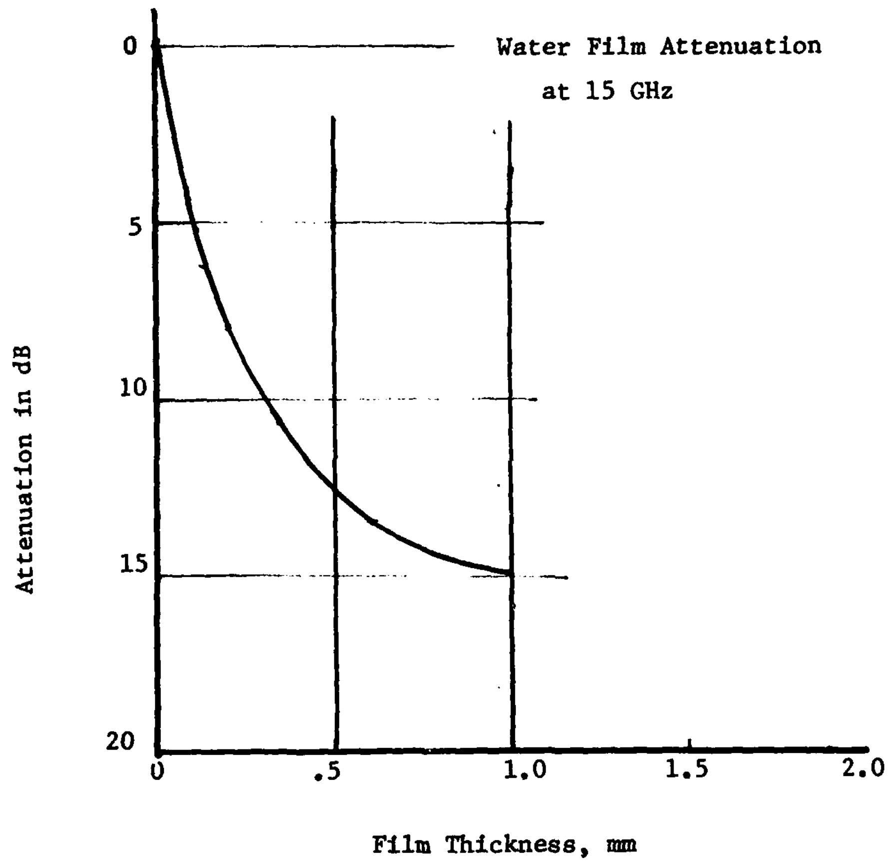

Figure 4: Transmission Through a film of water

(After Barnett 1972)

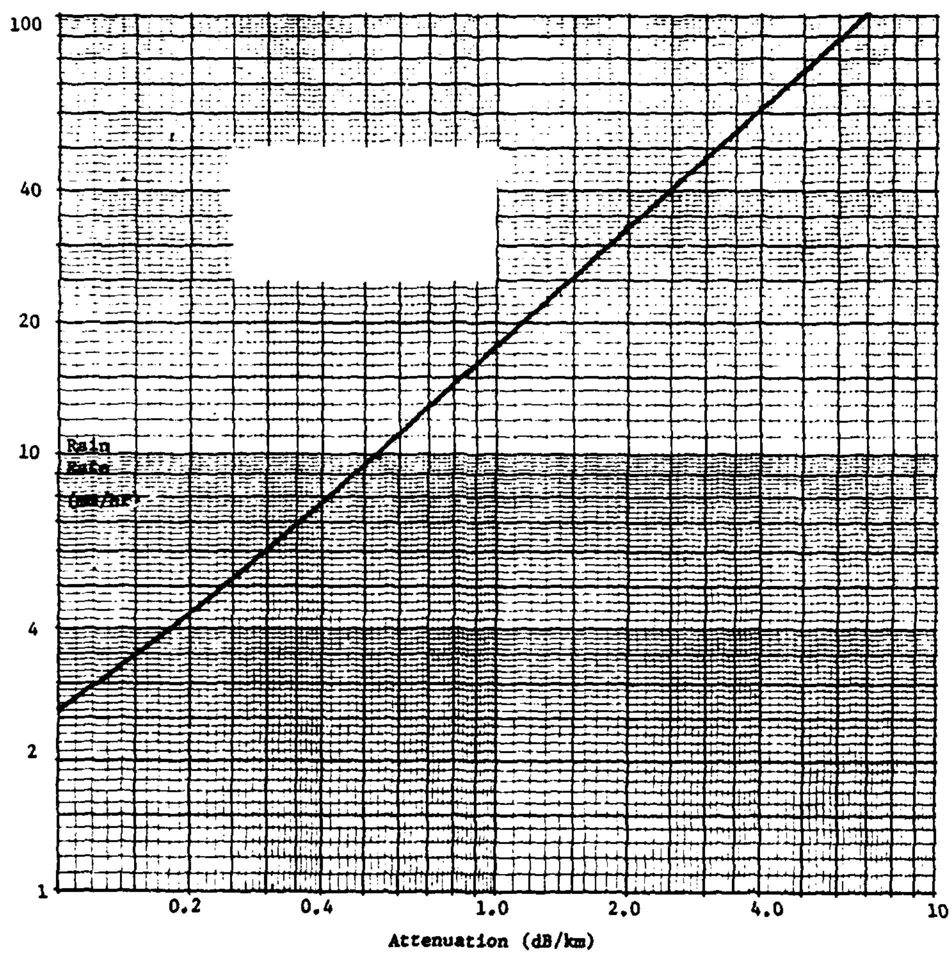

Figure 5. Rain Attenuation vs Rain Rate at 15 GHz.

Blwands, Denmark:	5.8 mm/hr
Karachi, Pakistan:	6.8 mm/hr
Kola USSR:	2.5 mm/hr
Hasphong, N. Vietnam	36 mm/hr
Hanoi, N. Vietnam	30 mm/hr
Saigon, S. Vietnam	40 mm/hr
Bangkok, Thailand	45 mm/hr
Kavalla, Greece	10 mm/hr
Pacific Ocean	4 to 40 mm/hr
Atlantic Ocean	7 to 40 mm/hr
Adana, Turkey	6 mm/hr
Sacramento, California	5.2 mm/hr
N. Platte, Nebraska	8 mm/hr
Capetown, S.A.	15 mm/hr
New Orleans, La.	50 mm/hr
Washington, D.C.	16 mm/hr
Portland, Oregon	11 mm/hr

Figure 6 gives the annual cumulative distribution of computed instantaneous rainfall rates for Washington D.C. This curve is representative of typical temperate zone coastal rainfall and is a good "average case" for the locations listed above. The rainfall rates presented in this figure will be used throughout this paper.

4. In order to determine the effect of rain on a communications network, a model of the expected rainstorms was formulated. A cylindrical rain cell model (Rogers, 1976)[10] is assumed. The diameter of the rain cell will vary with rain rate. Rogers states that all the curves indicate that the strong attenuations are associated with heavy rain that is generally less than 10 km in extent along the propagation path. Figure 7 presents curves of rain rate vs cell diameter at conditional probabilities of 0.5 and 0.25 for cell diameter vs rain rate (Yokoi, 1974).[11] Also are presented points from Harden (1974)[12] of rainfall rate as fraction of peak value vs cell diameter for rain rates in excess of 20 mm/hr. From these and other sources a model of rainfall has been formulated as follows:

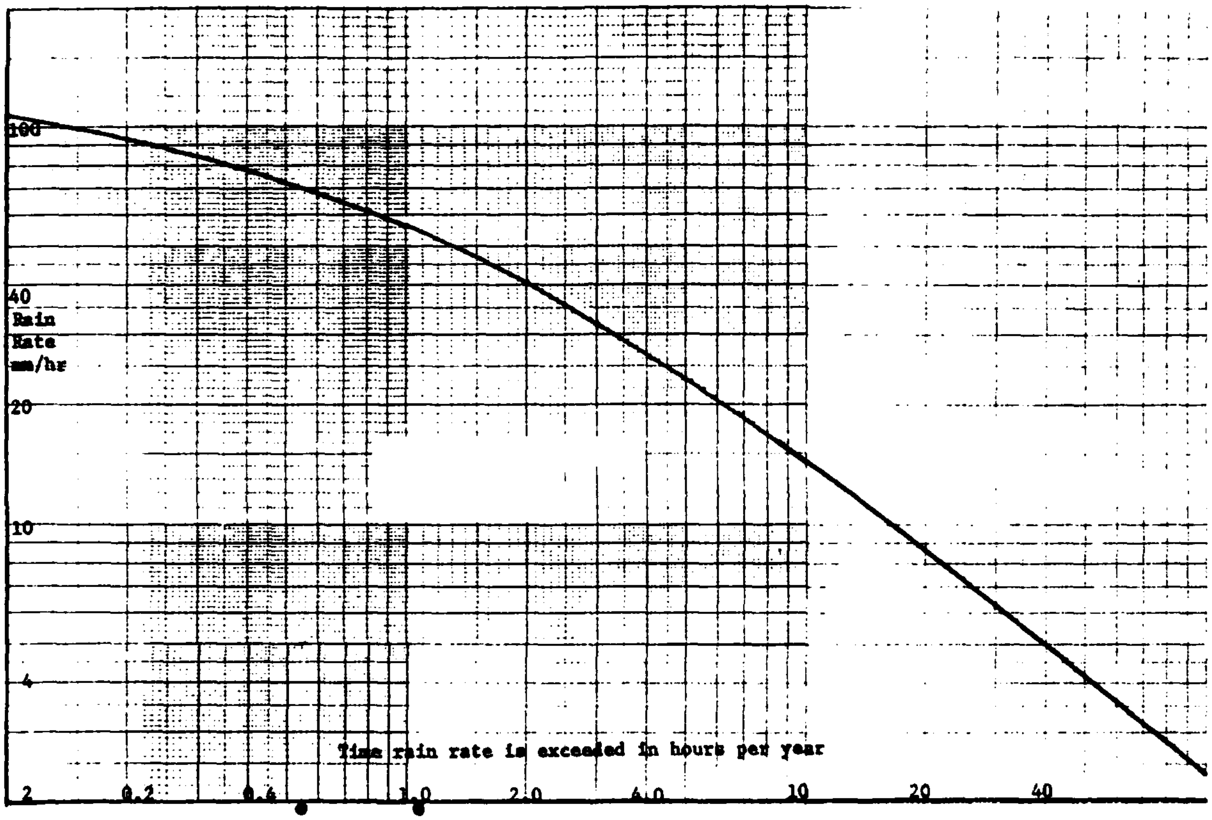

Figure 6. Cumulative Distribution of Rain Rate for Washington D.C.

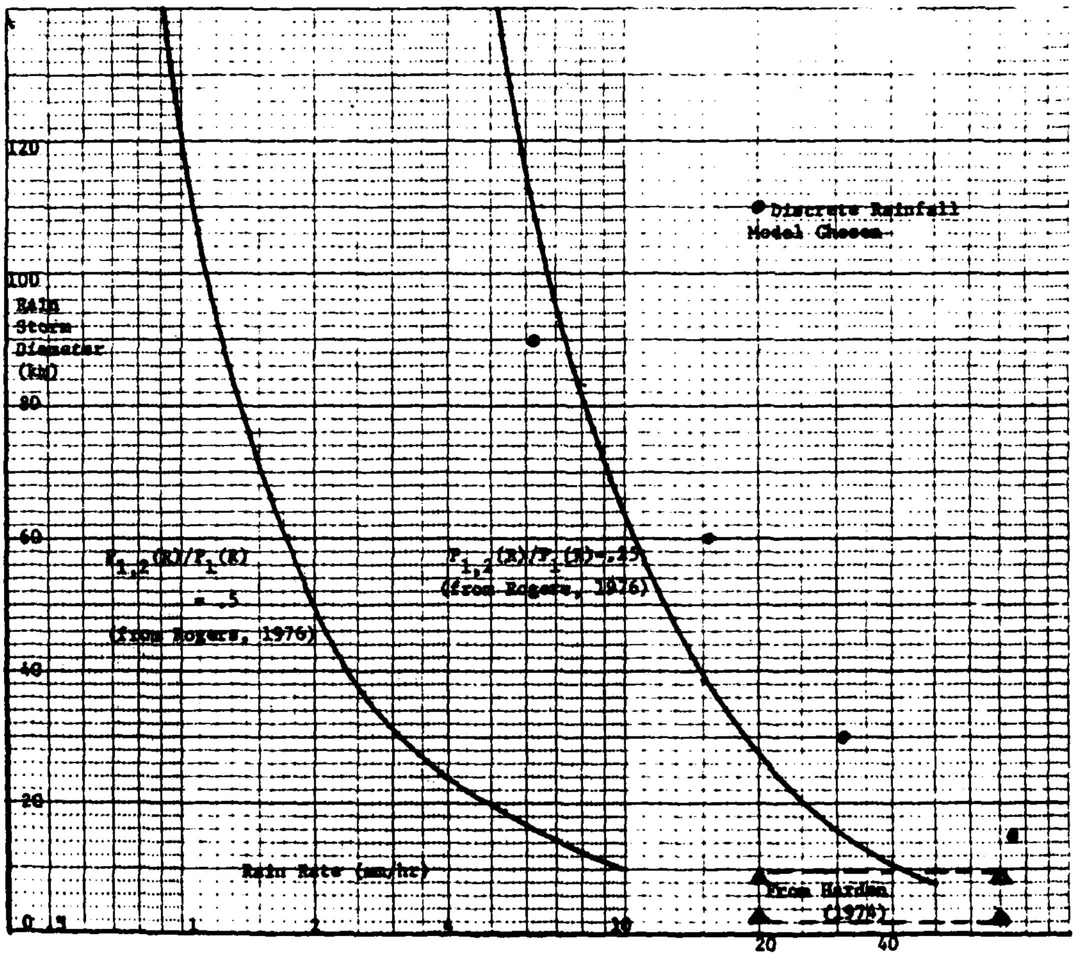

Figure 7. Discrete Rainfall Model Chosen

rain cell diameter (km)	rain rate (mm/hr)	rain duration (hours)	rain duration (% of year)
15	75	1	.011
30	32	3.5	.04
60	15.5	8.76	0.1
90	6.2	30	0.34
150	2.7	87.6	1.0
150 (or greater)	1.5	300	3.4

TABLE I. Rain Model

This model is based on rainfall statistics of Washington D.C. and yields an annual rainfall of 119.5 cm. The six rain cells are plotted in figure 7 for comparison with data from Rogers (1976) and Harden (1974). It will be seen that at the high rain rates the upper limit on rain cell diameter was chosen, while at lower rain rates, a somewhat smaller percentage of the total rainfall is assumed. This model should provide a somewhat pessimistic result for temperate zone conditions. If communications can be shown to be maintained with this rain model there should be a fairly high probability that in actual field experience the results will be favorable.

5. A typical deployment of the DMR is shown in figure 8. Path lengths are assumed to be 50 km, nominally, with some shorter. Two jammers are assumed, placed as indicated, approximately 100 km from the network. In order to determine the effect of rain on both the desired signal and on the jamming signal, the five values of rain cell diameter have been shown in figures 9-13. In each case the rainstorm passes directly across the communication network. In each case the time each desired signal path is in the rainstorm, the amount of time both jammer paths to any given terminal are disrupted by rain and the rain attenuation on each jammer and signal path has been determined. It should be noted that for rainstorms of 30 km or less, there is never a simultaneous reduction in both jammer signals to both terminals of a path. It is only when the storm diameter approaches the nominal path length (figure 11) that some jammer signal attenuation is simultaneously experienced from both jammers. Jammer signal attenuation of up to 30 dB is noticed in rare cases. At a storm diameter of 90 km most of the paths in the network are affected by rain attenuation. However, at this rain rate the maximum attenuation is 15 dB. The 150 km rainstorm envelopes the entire network. However, the rain is so light as to cause only a maximum of 5 dB path attenuation, in these cases.

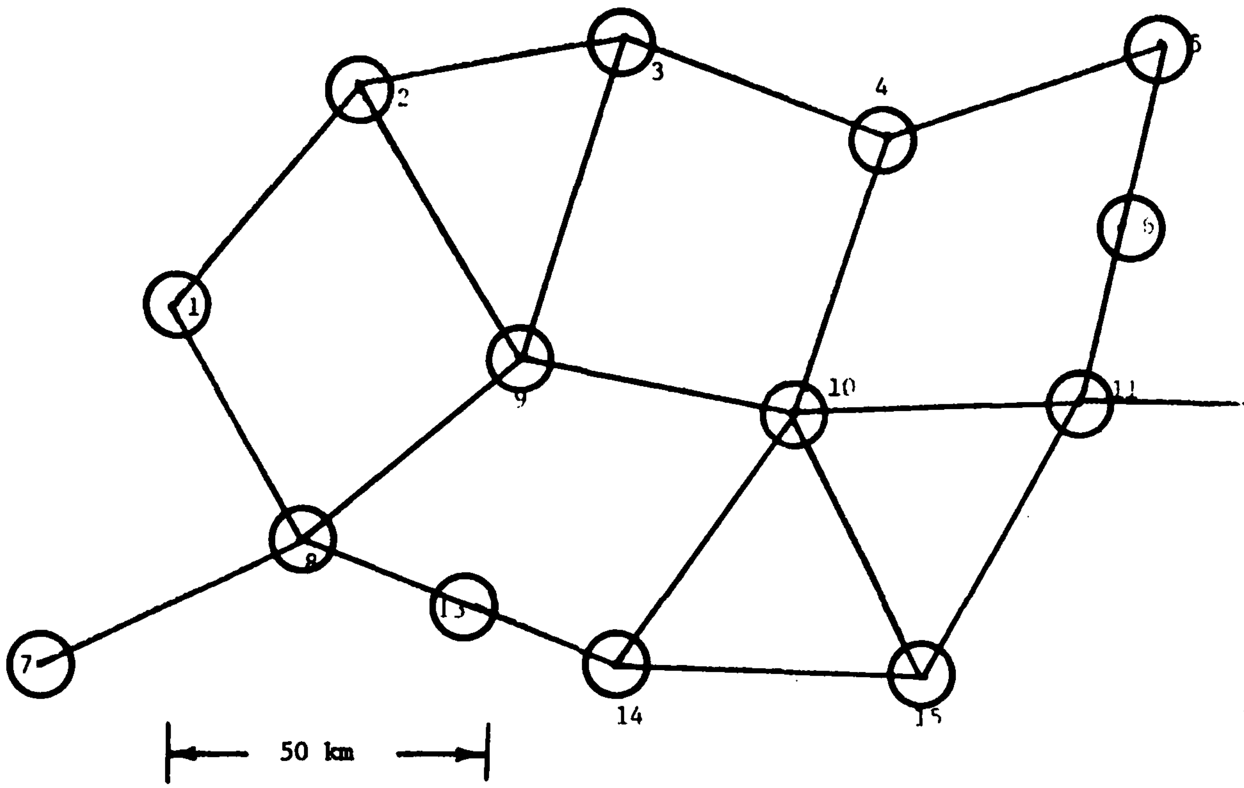

Figure 8. Typical Deployment of the Digital Microwave Radio

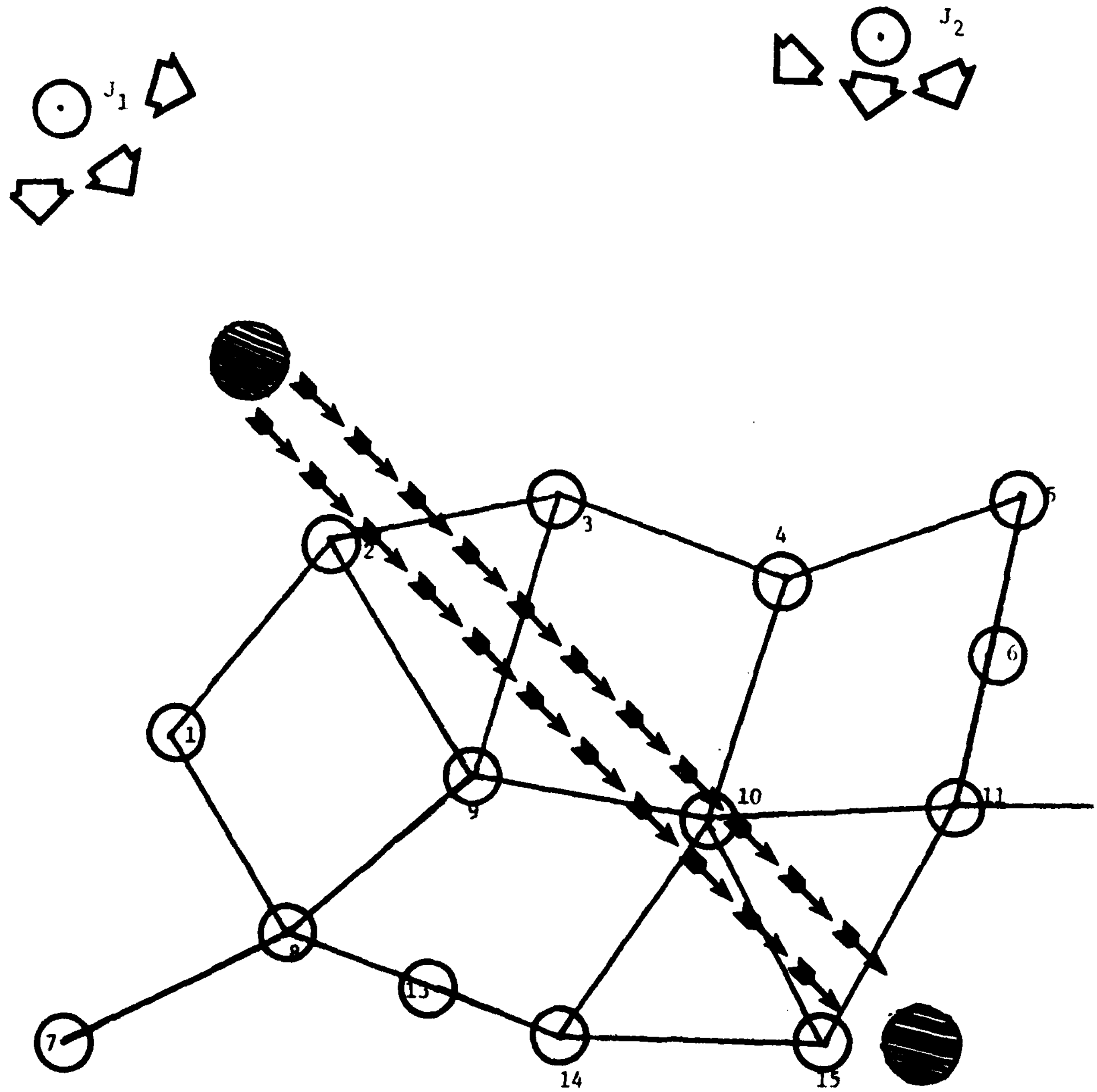

Figure 9. 15 km diameter Rain Storm

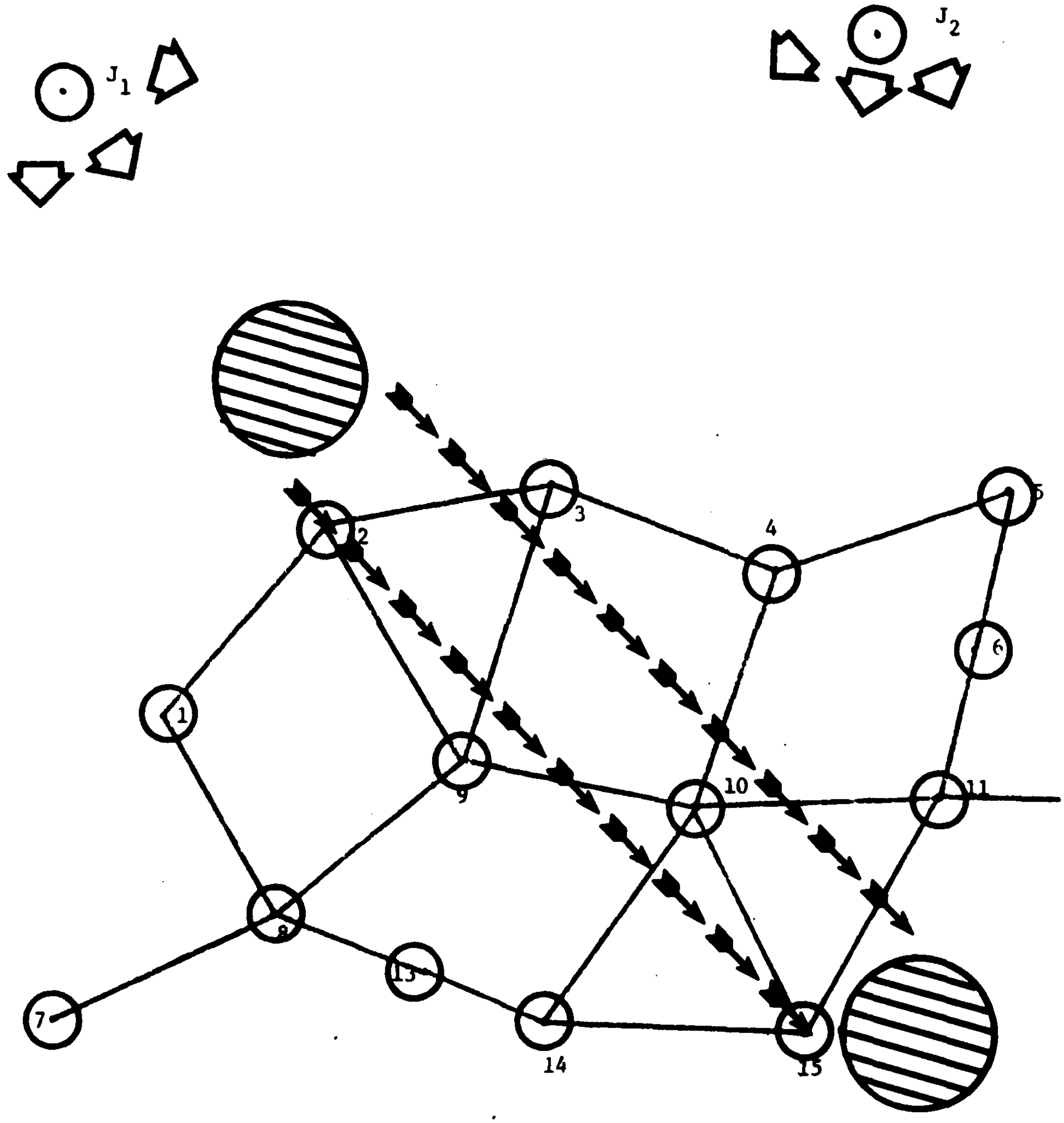

Figure 10. 30 km Diameter Rain Storm

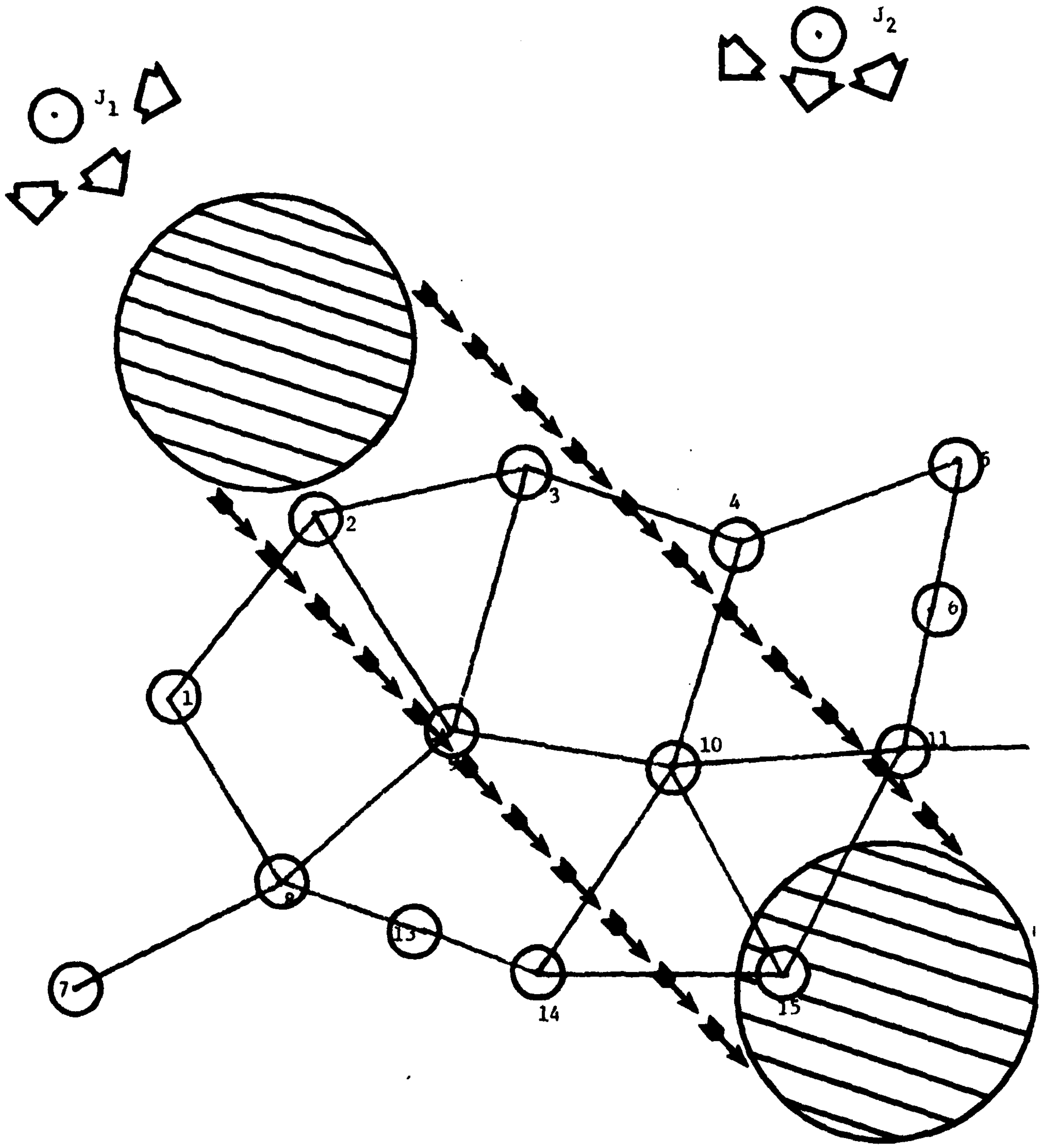

Figure 11. 60 km Diameter Rain Storm

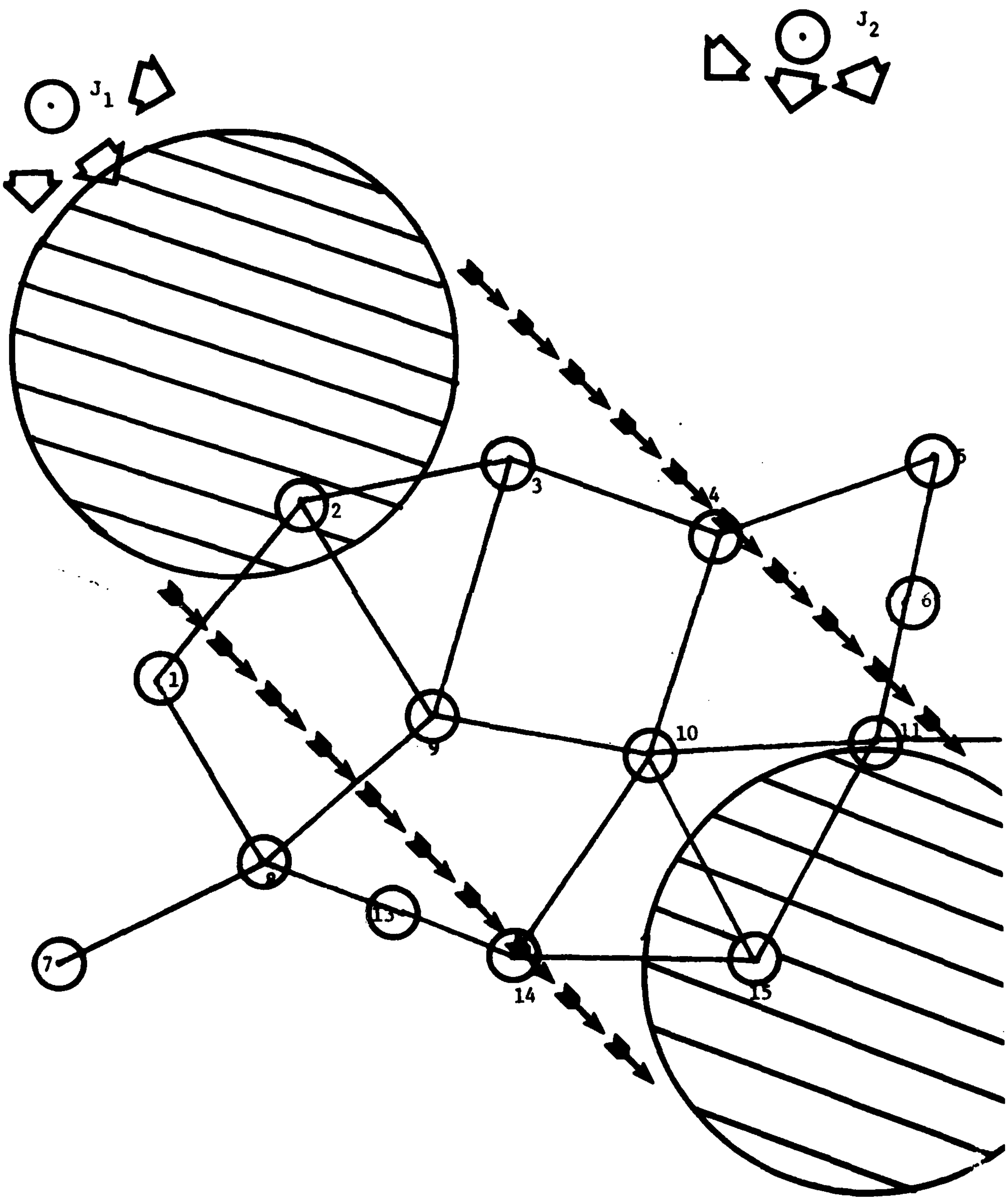

Figure 12. 90 km diameter rain storm

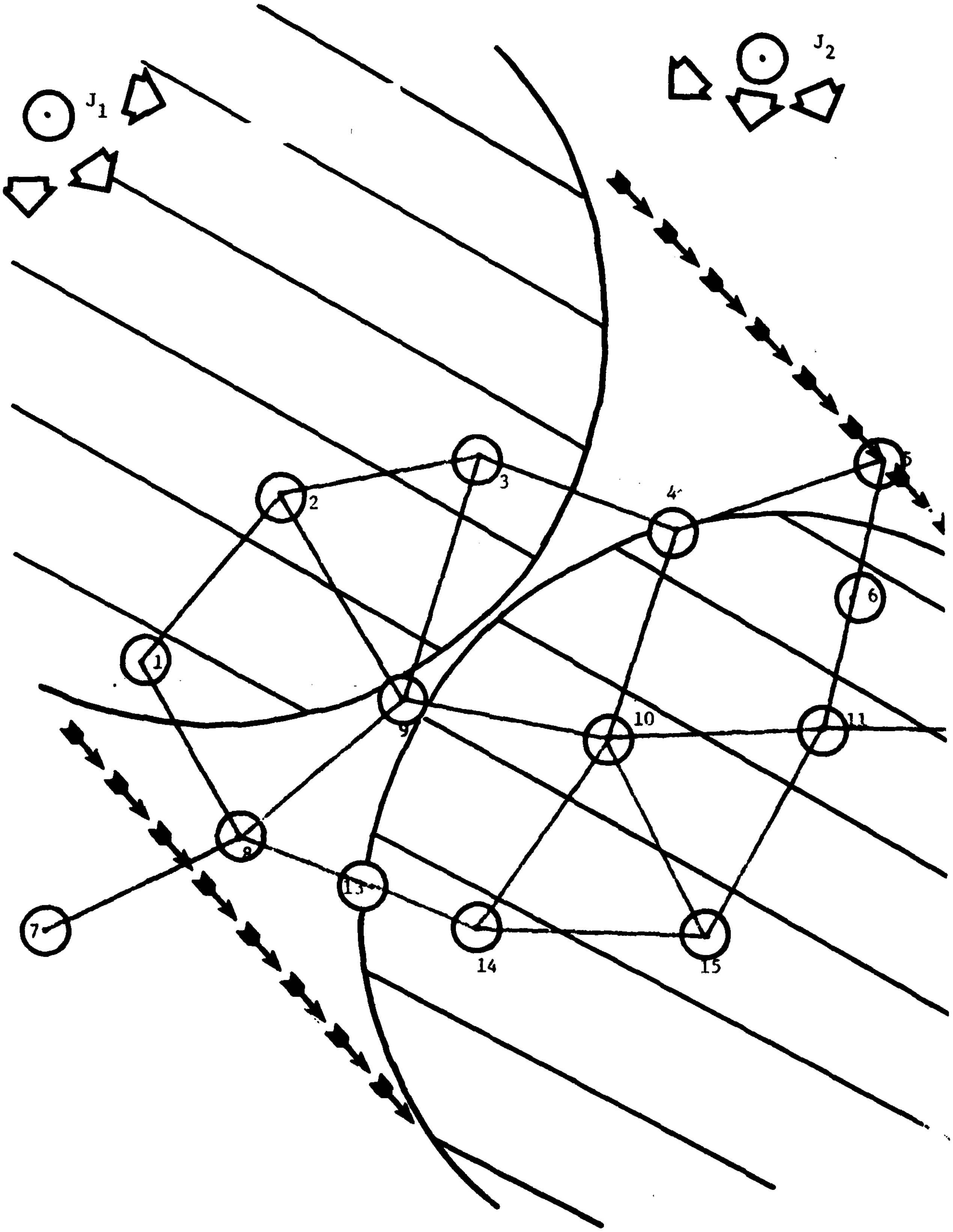

Figure 13. 150 km Diameter Rain Storm

The results of the rain model on the network communications are presented in figure 14. It can be seen that the desired signal attenuation for probabilities below .08% are less than would be calculated assuming the rainfall rate of figure 6 occurred simultaneously over the entire path. Since heavy rainstorms are small in size relative to the path lengths in question, the attenuation from these storms will be experienced over only a fraction of the path. The likelihood of occurrence of the rain cell intercepting the signal path is increased by this same factor, over the likelihood of occurrence at a terminal point.

It can be seen that the jammer power received from at least one of the two jammer sources is attenuated very little, compared with the signal. This is a result of the small likelihood of rain cells simultaneously covering a significant portion of widely separated paths.

Figure 14 indicates that the communications system designer would be required to provide 42 dB of margin to compensate for the difference in rain attenuation on the desired and the jamming paths to avoid outages of more than 0.1%. 55 dB of margin is required in order to reduce outages to .03% of the time.

6. In view of the high values of signal attenuation caused by rain at 15 GHz, it is proposed that alternate routing of signals be made during periods of heavy rain. Rogers (1976) states, "Since the most intense rain is confined to relatively small cells, it is recognized that switched-path diversity provides a method for improving the reliability of satellite and terrestrial communication systems." In figure 15 an alternate route is indicated for each path within the network (excluding extensions 7-8 and 11-12). The effect of rain attenuation on the parallel combination of direct and alternate route for each path has been determined for each rain cell size and rain rate. The result of this determination is shown in figure 16. It can be seen that the required margin to compensate for the difference in rain attenuation on the desired and the jamming paths is reduced to 24 dB for 0.1% outages and 32 dB for .03% outages. The use of alternate routing, therefore, provides from 18 to 23 dB reduction in the required margin to overcome rain attenuation on this jammed communications network.

a. The oxygen and water vapor losses have been found to reduce the jamming to signal ratios (J/S) by 4.2 dB (exceeded 1% of the time) to 1.4 dB (exceeded 50% of the time). Fog will also reduce the J/S for small periods of time by up to 2.4 dB. However, these losses are small compared to rain losses and since rain loss statistics in general are not reported with these losses subtracted out, they should not be added to calculate margins during rain.

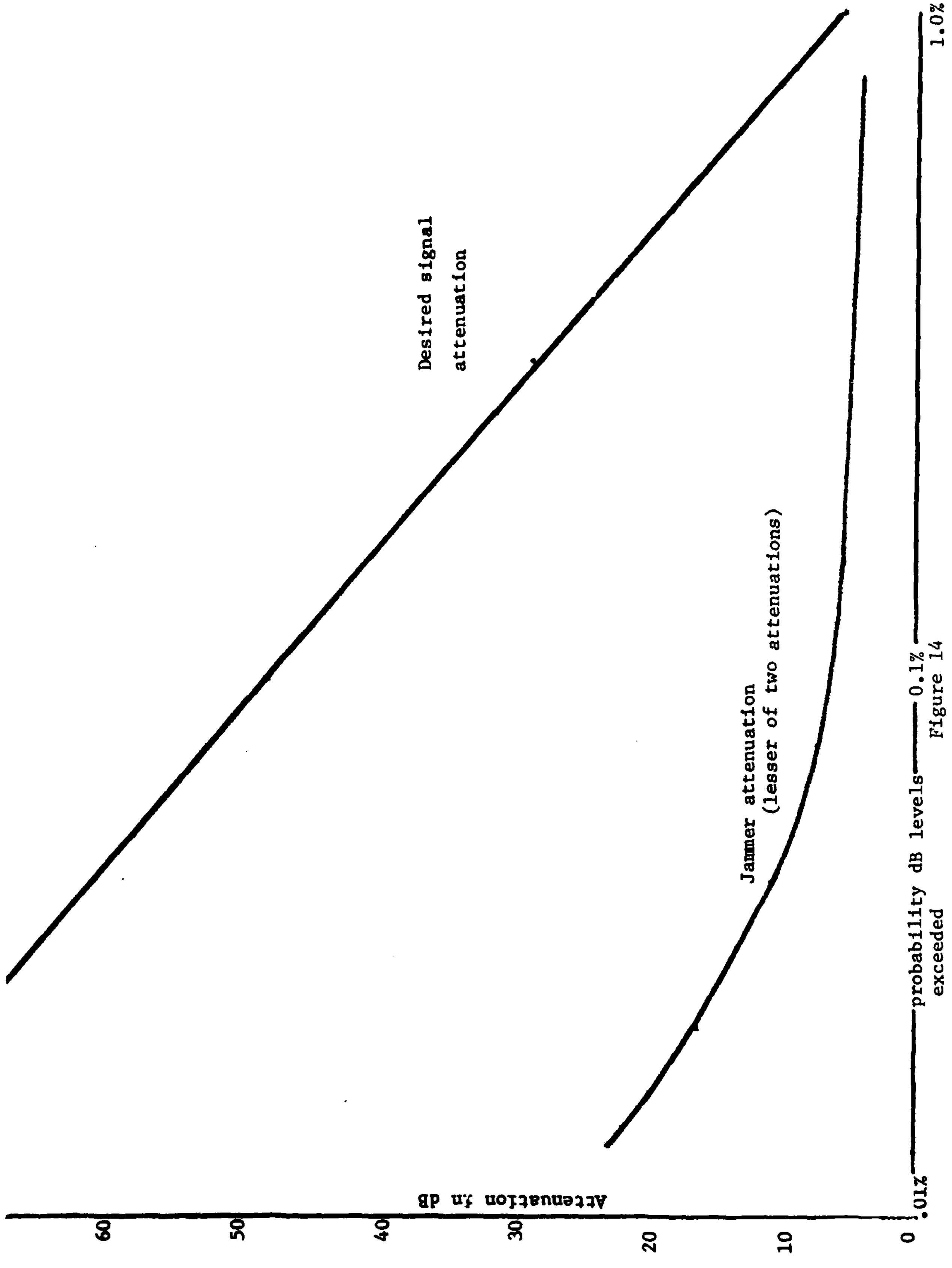

Figure 14. Effect of Rain on Network Communications

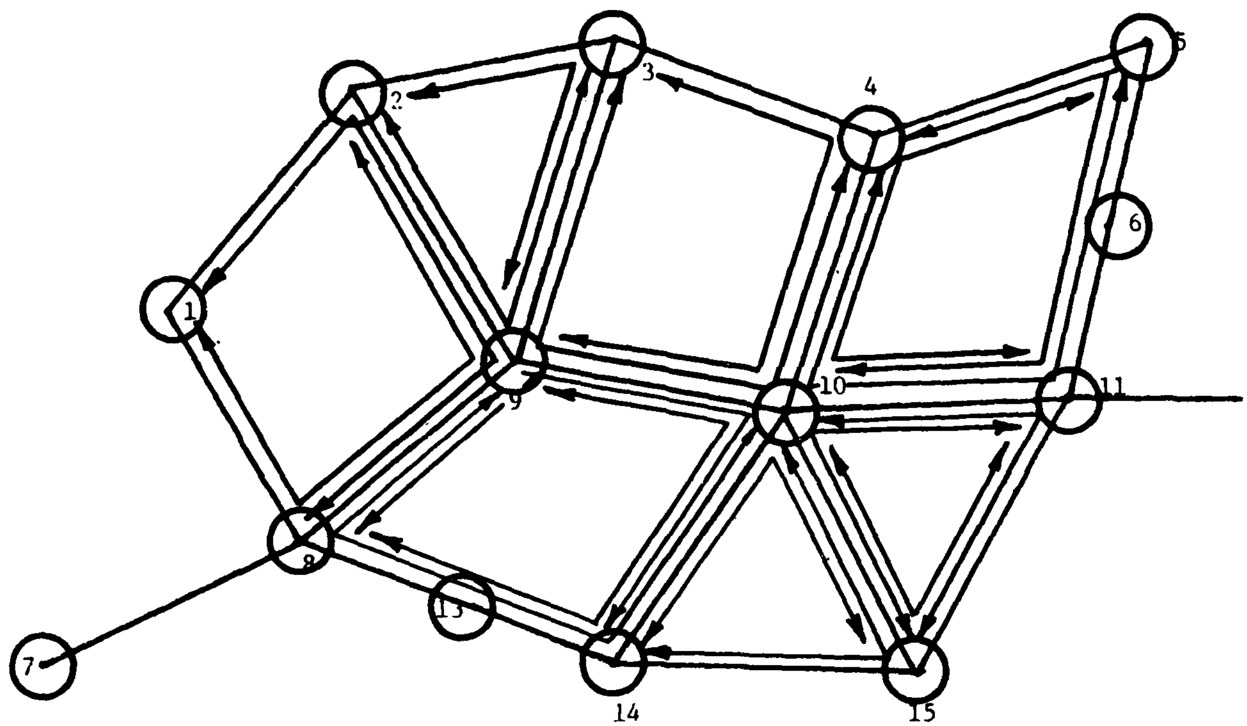

Figure 15. DMR Multiple Routing Technique

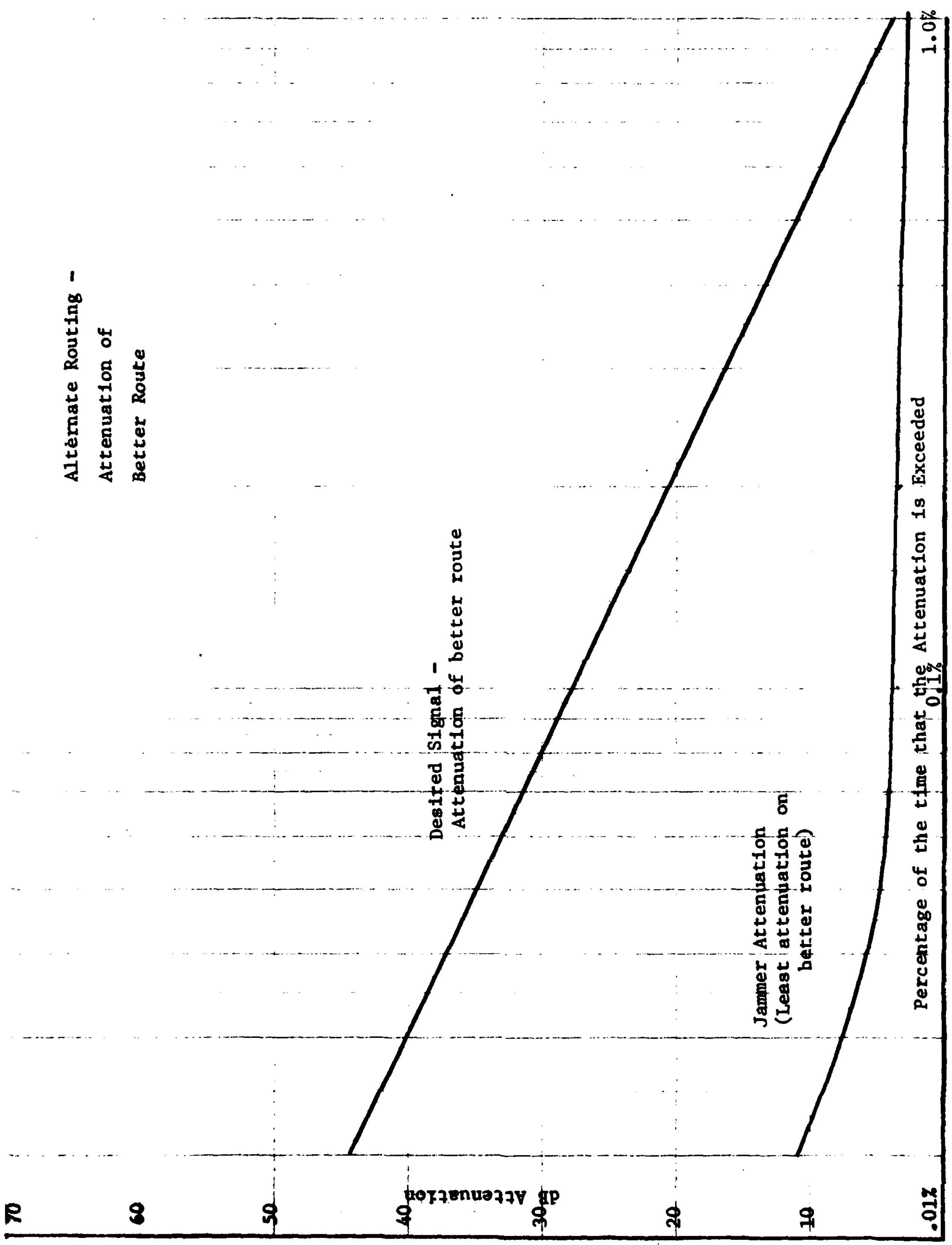

Figure 16. Alternate Routing - Attenuation of Better Route

The method employed to combine the fading effects of rain and multipath will be based on the assumption that these effects will not occur simultaneously. There is evidence to indicate that severe multipath is most likely on clear nights. Therefore it is reasonable to design our radio circuits to operate with fades which occur for the sum of the fading periods of multipath and of rain. The combined effect of multipath and rain is shown in figure 17. It can be seen that the required fade margin for 0.1% of the time has increased by approximately 0.5 dB from the rain margin (figure 19). The fade margin for 0.03% of the time is the same as the rain margin. Since the jammer attenuation will not be increased any significant amount of time, the curve remains unchanged. Note that during the 10% of the time that the jammer signal may be enhanced by multipath, no rain is likely in the area. Therefore the system margin against rain and multipath should be sufficient to negate this enhancement.

The reduction in combined rain and multipath fade margin as a result of alternate routing is shown in figure 18. It is seen that a 28 dB fade margin (24.5 dB J/S margin) is required for 0.1% outages and a 40 dB fade margin (32 dB J/S margin) is required for .03% outages.

7. Conclusions. It has been shown that the performance of a 15 GHz communication network in an ECCM environment is affected by rain attenuation and multipath fading. It is noted that the rain attenuation increases with rain rate, while the average size of a rainstorm reduces with rain rate. Typically a thunderstorm will cover an area of 5 km or less. Most rain cells that must be considered in providing system fade margin, will cover only a portion of the communication path. The path attenuations from rain cannot, therefore, be calculated directly from point rainfall data since it is unlikely that the entire radio relay path (nominally 50 km in the case under consideration) will be in rain. By the same token, there is a far greater likelihood that a portion of the path will be in a heavy rainstorm than the terminal. The result of this rain distribution is that there will be more paths experiencing rain than terminals but that the average rain rate over a path will be less than that predicted from the point rainfall statistics.

The jamming signal path has been shown to be far less affected by rain attenuation than the signal path. This is to be expected since two widely separated jamming sources were assumed. The likelihood of simultaneous heavy rainstorms between a receiver location and both jammer locations is small.

Alternate routing of signals through the network offers significant reduction in the required signal margin to overcome multipath and rain fading while under jamming attack. It has been shown that without alternate routing a 71 dB margin is required (55 dB J/S margin) to maintain communications 99.97% of the time. However, with alternate routing the required margin is reduced to 40 dB (32 dB J/S margin). Certainly the advantages of alternate routing cannot be overlooked in the design of a 15 GHz line-of-sight radio network.

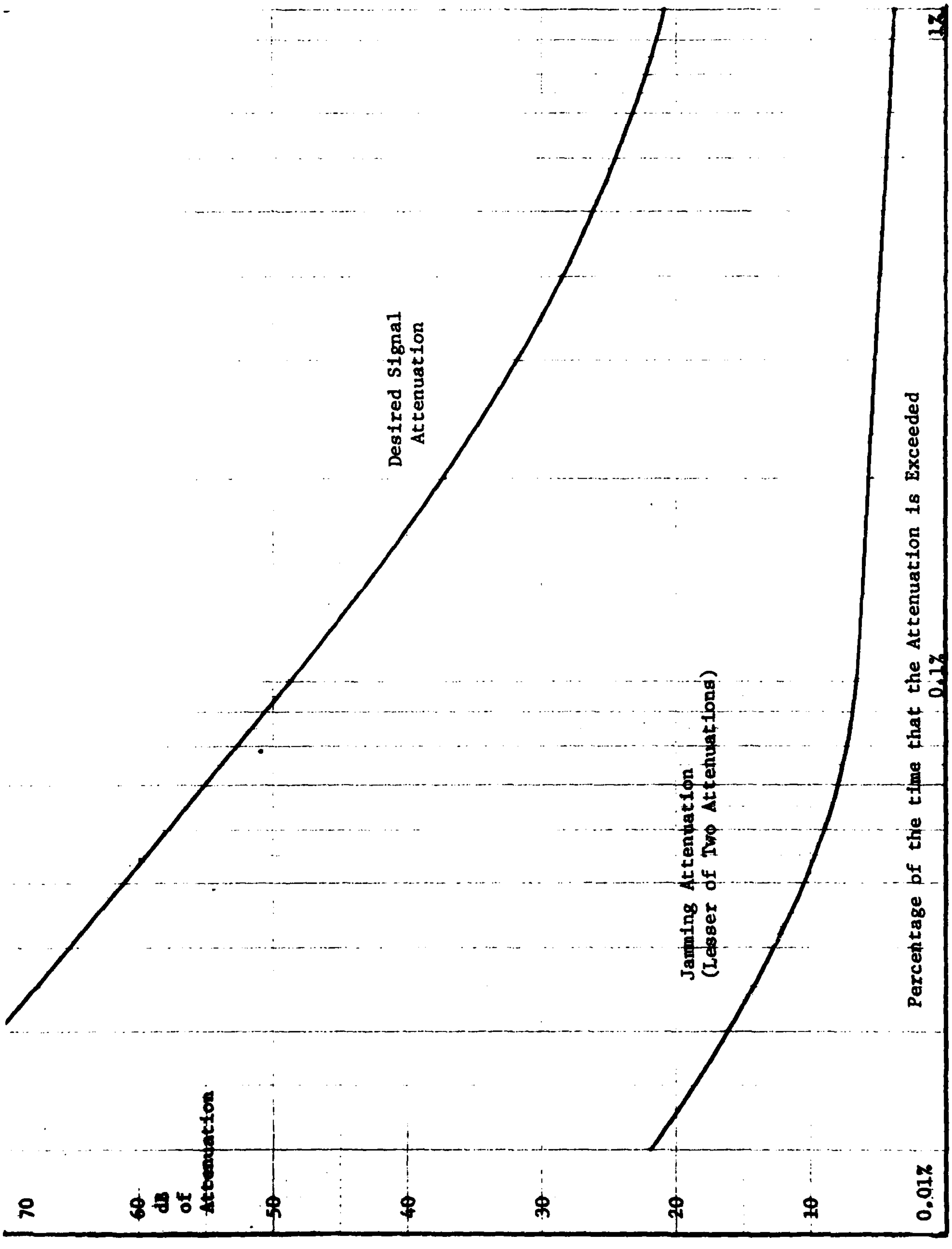

Figure 17. Combined Effect of Multipath and Rain at 15 GHz

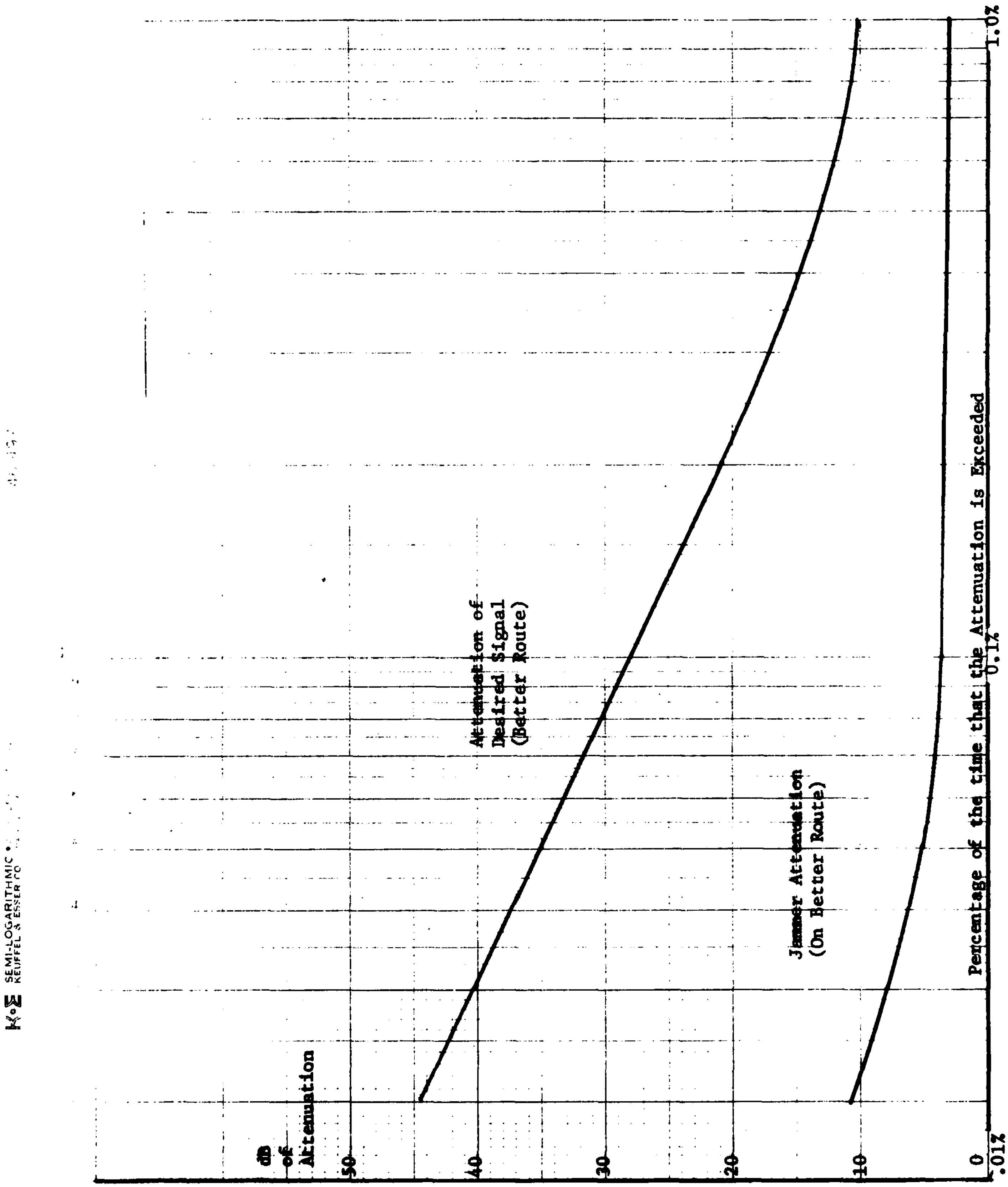

Figure 18. Alternate Routing Combined Rain and Multipath Fading (Attenuation of Better Route)

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